Indian J. Phys. **78(8)**, 845-847 (2004)

AN INTERNATIONAL
IJP

Lifetime of minority charge carriers in MoS_xSe_{2-x} layered compounds

A K Shah

Sheth R A Bhavan's Science College, Khanpur, Ahmedabad-380 001, Gujarat, India

E-mail : atzeel@yahoo.com

Abstract : The study on measurement of lifetime of the minority charge carriers in grown crystals of transition metal dichalcogenides (TMDC) material MoS_xSe_{2-x} has been reported for stoichiometric variation $X = 0, 0.5, 1, 1.5$. The electrical field excitation method has been used for illuminating of the single crystal MoS_xSe_{2-x}. The lifetime of minority charge carriers have been evaluated from the analysis of exponential decay curve of the output voltage traced under swiping mode of CRO. It is found from the present investigation that as X in the MoS_xSe_{2-x} TMDC layer compounds increases, the lifetime of the charge carrier is also increases. The possible causes of such dependency of the lifetime of charge carriers on the stoichiometric variation in such TMDC layer compound are explained.

Key words : Life time, TMDC material.

PACS No. : 68.55.-a

1. Introduction

The single crystal of transition metal dichalcogenides have generated considerable amount of interest. Structurally, this compound is found by stacking 'Sandwiches' consisting of a layer of transition metal atoms between two layers of chalcogen atoms. There is strong covalent bonding within the sandwich layers, but weak Van der Waal bonding between them. This crystalline anisotropy leads to anisotropy in electrical property, which opens the door for its diverse application such as catalyst, batteries and lubricant. These single crystals are also used in photo-electro chemicals solar cells, optoelectronic devices *etc.* TMDC compounds are having layered structure which, possesses semiconductor properties. The TMDC compound allows the process of intercalation or insertion of foreign atoms and molecules into host materials, thereby altering the structure and electronic behaviour [1–8]. In optoelectronic device charge carriers are injected by external electric field, hence measurement of lifetime of such excess carriers is of the vital interest in characterization of material. In present paper the lifetime of minority carriers in $MoSe_2$, $MoS_{0.5}Se_{1.5}$, MoSSe and $MoS_{1.5}Se_{0.5}$ TMDC compounds are reported using electrical excitation method.

2. Experimental procedure

In the present work, all the compounds were synthesized directly from the elements using direct vapour transport (DVT) method. Appropriate amount of powder were weighted accurately for desire composition and mixed intimately to give homogeneous mixture. The best quality fused quartz ampoule was cleaned thoroughly. The proper procedure for cleaning and sealing of ampoule was adopted. The seal ampoule was introduced into two-zone pre-calibrated furnace at constant temperature to obtain the charge of the compounds. The charge so prepared was rigorously shaken to ensure proper mixing of constituents and kept in the furnace under appropriate condition to obtain the single crystals. We have grown the series of $MoSe_2$, $MoS_{0.5}Se_{1.5}$, MoSSe and $MoS_{1.5}Se_{0.5}$. Single crystals are characterized for structural data. The above crystals are used to measure the lifetime of minority

© 2004 IACS

charge carriers. The experimental set up used for measurement of lifetime is shown in the Figure 1.

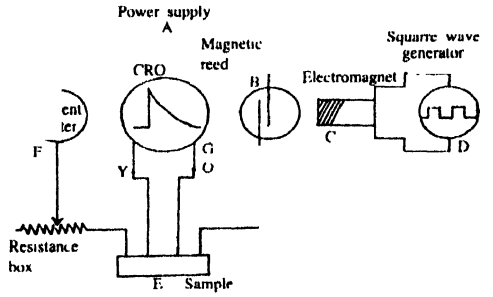

Figure 1. Schematic diagram of experimental setup.

The sample of TMDC was mounted on glass slide and four-equidistance contacts were taken out along a line. Two contacts are used, for input electrical excitation and two for measuring the output waveform on CRO The magnetic reed provides rectangular current pulse to sample (during its on state) causing almost vertical rise of the spot on CRO. When reed goes to off state the generated charge carrier decay exponentially causing decay curve on CRO. In thermodynamic equilibrium, the electron and hole density of a grown crystal remains constant with respect to time. This density can be 'up set' by subjecting to external excitation and after removal of the excitation of the field, the restoring process takes place, which reestablish the original equilibrium density in time.

3. Results and discussion

The decay curve observed for TMDC materials MoS_xSe_{2-x} are shown in Figure 2.

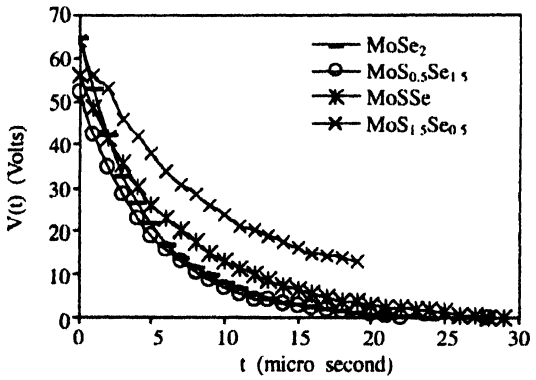

Figure 2. Decay of life time of minority charge carriers in MoS_xSe_{2-x}.

The analysis of the curve fits to the exponential nature as

$$V(t) = Vo \exp(t/\tau). \quad (1)$$

Here $V(t)$, Vo and t are voltage at time t, maximum voltage at $t = 0$ and τ is the life time of the minority charge carriers. This leads to the relation for lifetime of charge carriers as

$$\tau = -t/\ln [V(t)/V(o)] \quad (2)$$

So, we have plotted in Figure 3 the curve of $t \rightarrow \ln [V(t)/V(o)]$ to obtain the life time from the slope of the curve.

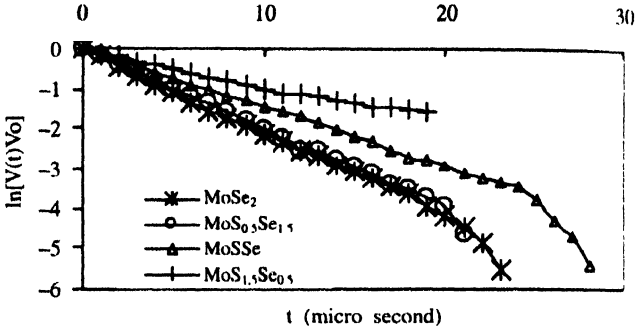

Figure 3. Logarithmic curves of decay of life time of minority charge carriers.

Thus obtained lifetimes for various TMDC samples are shown in Table 1 alongwith resistivity, Hall mobility, Hall coefficient, carrier concentration and optical band gap for respective samples of TMDC compounds [1,8].

From the careful analysis of results, following conclusion can be made :

As the concentration X of the sulphur increases, the life time of the minority charge carriers of material increases. The resistivity against lifetime obey linear relation $\rho = 1.1907\tau - 3.346$ with $R^2 = 0.9943$ (Figure 4).

This suggests that lifetime of minority charge carriers in the TMDC compounds is directly proportional to the resistivity of material. The Hall mobility *verses* lifetime of the aforesaid compounds follows the polynomial relation of the degree two (Figure 5).

Table 1. Resistivity, Hall mobility, Hall coefficient, carrier concentration and optical band gap for respective samples of TMDC compounds.

Compound	Life time micro sec	Resistivity ohm-cm	Hall mobility cm^2/volt-sec	Hall coefficient	Carrier concentration cm^{-3}	Optical band gap eV
$MoSe_2$	4.6648 ± 0.1651	1.98	54.3	-108.7	5.73 *E* + 16	1.36
$MoS_{0.5}Se_{1.5}$	5.0142 ± 0.0755	2.8200	62.3	-175.7	3.55 *E* + 16	1.475
MoSSe	6.7753 ± 0.1270	4.4200	83.7	-370.2	1.69 *E* + 16	1.57
$MoS_{1.5}Se_{0.5}$	10.08 ± 0.53	8.6300	85.8	-740.7	0.885 *E* + 16	1.67

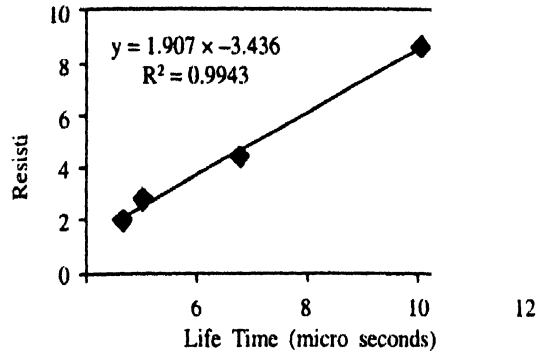

Figure 4. Resistivity against life time of minority charge carriers.

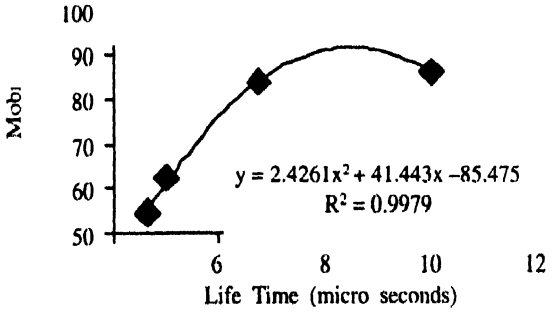

Figure 5. Hall mobility against life time of minority charge carriers.

The Hall coefficient *verses* lifetime also follows linear relationship (Figure 6). The carrier concentration against lifetime predicts power curve (Figure 7). The optical

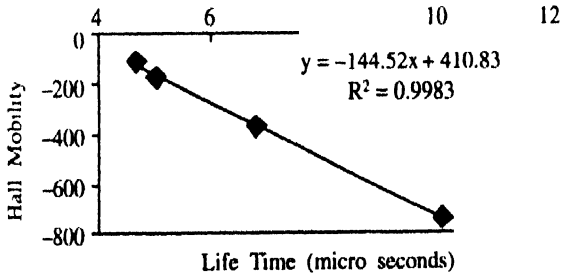

Figure 6. Hall coefficient against life time of minority charge carriers.

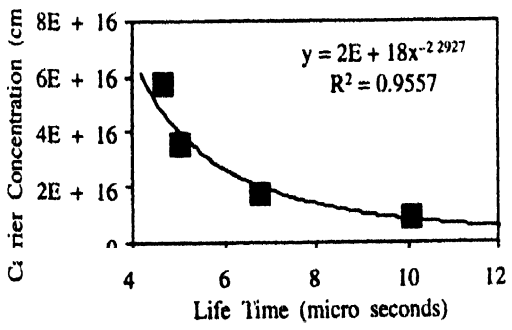

Figure 7. Carrier concentration against life time of minority charge carriers.

band gape *verses* lifetime obeys the polynomial relation of the degree two (Figure 8). Here, higher the optical band gap, higher the life time of the minority charge carriers of the material.

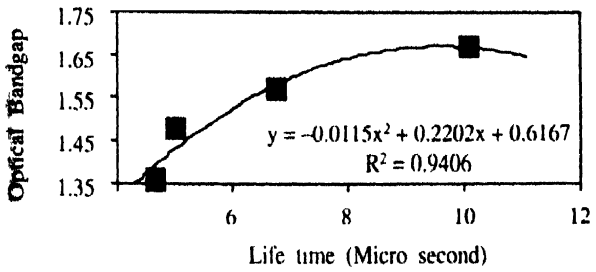

Figure 8. Optical band gap against life time of minority charge carriers.

4. Conclusions

At the end, we conclude that the life time of the minority charge carriers in TMDC compounds can be adjusted to the required value by controlling the density of the recombination centers. It is difficult to long life in low resistivity material, as density of the impurity is low. The results for $MoSe_2$, WSe_2, $SnSe_2$ and $Mo_{0.2}W_{0.8}Se_2$ (TMDC) compounds are also confirms all the above conclusions [9].

References

[1] A K Shah *Growth of Layer Compound – Analysis of Exponential Decay Waveforms, M. Phil. Dissertation* (Sardar Patel University, Gujarat) (1992)

[2] G V Subba Rao *Intercalated Layered Material* (D Reidel) p99 (1979)

[3] A G Milnes *Semiconductor Device and Integrated Electronics* (New Delhi, India : CBS Publishers) (1987)

[4] H Tributch *J. Electrochem. Soc.* **125** 1086 (1978)

[5] A J Barreta, A Vazaquer and E Comarilla *J. Crystal Growth* **96** 685 (1989)

[6] M P Deshpande, P D Patel, M N Vashi and M K Agarwal *J. Crystal Growth* **197** 833 (1999)

[7] M K Agarwal, P D Patel and S K Gupta *J. Crystal Growth* **129** 559 (1993)

[8] M K Agarwal and L T Talele *Mater. Res. Bull.* **20** 329 (1985)

[9] A K Shah *Proc. NASAEM* (Bilaspur, India) (to be published) (2003)